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VIEWPOINT

Waste Management and Climate Change[1]

FRANK ACKERMAN

ABSTRACT *Waste management has at least five types of impacts on climate change, attributable to: (1) landfill methane emissions; (2) reduction in industrial energy use and emissions due to recycling and waste reduction; (3) energy recovery from waste; (4) carbon sequestration in forests due to decreased demand for virgin paper; and (5) energy used in long-distance transport of waste: A recent USEPA study provides estimates of overall per-tonne greenhouse gas reductions due to recycling. Plausible calculations using these estimates suggest that countries such as the US or Australia could realise substantial greenhouse gas reductions through increased recycling, particularly of paper.*

Introduction

Discussion of the causes of climate change usually begins with energy consumption, as it should, but too often ends there as well. It is certainly true that most anthropogenic emissions of greenhouse gases result from the combustion of fossil fuels. Yet it is important to look at the climate change impacts of other environmental concerns, such as waste management, for two reasons. First, there are some significant non-energy sources of greenhouse gases, including the emission of methane from landfills; and secondly, choices and policies in the realm of waste management have a surprisingly large effect on the ways in which we use energy.

Waste is not only a large contributor to the greenhouse problem; it is also an area where doing the right thing for the environment is politically popular. It is much easier to persuade most people to change the way they handle solid waste than, for example, to get them to drive sensibly small, fuel-efficient cars. Thus waste management is a promising area in which to pursue a reduction in carbon emissions, and should be part of any comprehensive strategy for climate change mitigation.

In this brief paper a framework is presented for the analysis of the greenhouse impacts of climate change; then some estimates of the size of the impacts based on recent US research are offered; and finally, approximate calculations of the importance of these impacts for Australia and for the USA are made. In view of the many uncertainties and approximations that must be made along the way, the numbers that result are not reliable bases for policy-making, but, I hope, serve to demonstrate that there is something big enough to justify an analysis in greater detail and precision.

Five Categories of Impacts

How does waste management affect greenhouse gas emissions? There are at least five categories of impacts to consider. The first and most obvious is landfill methane emissions. The latest estimates for both Australia (Australian Greenhouse Office, 1999) and the USA (US Environmental Protection Agency (EPA), 1999a) suggest that landfill methane accounts for about 4% of all greenhouse emissions,

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measured in terms of global warming potential. Most or all of the organic waste in landfills decays anaerobically, and most of the carbon is gradually released to the atmosphere, about half of it as carbon dioxide and half as methane. The latter is the problem: the same amount of carbon has a global warming potential 21 times greater if it is released as methane rather than carbon dioxide.

This impact is unmistakably caused by modern waste management. When waste ends up as litter, or in small, uncontrolled, uncompacted dump sites, there are potentially severe problems of sanitation, public health and aesthetics, but the decay of waste under these conditions is aerobic, releasing virtually all of its carbon as carbon dioxide rather than methane. As low-income countries develop, they will increasingly move from the open dumping of wastes to sanitary landfilling, implying that landfill methane emissions will be a growing problem world-wide in the future.

The other impacts are, for the most part, less visibly part of the waste management process. However, they are still caused by the decisions we make about waste and materials. Most important is the fact that both recycling and waste reduction lead to decreased energy use and process emissions in industry. The Intergovermnetal Panel on Climate Change (IPCC) estimates that primary (virgin material) production causes 40 times the greenhouse emissions of secondary (recycled material) production per tonne of aluminium. For many other industrial materials, primary production emissions are 4–5 times as great as secondary emissions per tonne (IPCC, 1996)

Most of this saving reflects the change in industrial energy use. Extractive industries such as mining, and basic materials industries such as metal, paper and plastics production, are the most energy-intensive branches of industry, using far more energy per dollar of output than later stages of manufacturing. For example, most of the energy required to make motor vehicles is used to extract raw materials from nature and process them into bulk industrial commodities. Much less is used to shape the materials – i.e. to fabricate car parts and assemble them. Recycling of raw materials, or using less to begin with, reduces energy use and associated carbon emissions in the most energy-hungry branches of industry.

A third type of impact arises when energy recovery from waste displaces fossil fuel consumption. This can occur through incineration, through other energy recovery technologies such as pyrolysis, and through the capture of landfill gas. Controlling landfill gas has a double benefit: landfill methane can be substituted for natural gas, a fossil fuel, and combustion converts methane to carbon dioxide, vastly reducing its greenhouse impact. For the same reason, even the simple technique of flaring landfill gas, i.e. burning it without capturing the resulting energy, is of great benefit from a climate change perspective.

At first glance, it is hard to see why there is a climate change benefit to burning waste paper in an incinerator instead of coal in a conventional power plant. Both combustion processes release carbon dioxide into the air. However, paper comes from trees, which absorb carbon dioxide from the atmosphere as they grow. Assuming sustainable forestry practices (a controversial assumption, but not one that will be pursued here), the emissions from burning paper will be balanced by the growth of new trees, leading to zero net emissions over the paper life cycle. This assumption is standard in climate change analyses. A parallel assumption can be made, perhaps less controversially, for incineration of other materials of recent biological origin, such as garden waste and food waste.

In contrast, fossil fuels are not renewable on any relevant time scale; their combustion does, therefore, lead to a net increase in atmospheric carbon dioxide. Among ordinary solid wastes, the same is true only for plastics, which are made from fossil fuels. So when a waste-to-energy facility substitutes for a fossil-fuel-burning power plant, the appropriate comparison is between the carbon dioxide emissions from plastic wastes (only a fraction of the incinerator's feedstock) and the emissions from all of the fossil fuel. Based on this comparison, a recent analysis of the paper life cycle in Australia (Pickin & Yuen, 1998) concludes that while paper recycling, composting and landfill gas recovery are all effective means of reducing greenhouse gas emissions, incineration of paper with energy recovery is the most effective. Similar conclusions have been reached in several, though certainly not all, studies in other countries.

Varieties of Sequestration

A fourth category of impacts also depends on complex hypotheses about forestry and other environmental policies: paper recycling and reduction may have an effect on carbon sequestration in forests. Any decrease in the production of virgin paper means that fewer trees need to be cut down. Hence, depending on assumptions about other factors that affect forest practices, there may be more carbon left standing in the woods.

A recent USEPA study of waste and climate change (USEPA, 1998a) employed an intricate series of forestry and paper industry models to estimate the sequestration effect. (I was a member of the large research team for that study, though I was not involved in the sequestration analysis.) The forestry models essentially showed that an increase in recycling or source reduction of paper leads immediately to decreased timber harvesting, implying an increase in the volume of wood standing in the forests. Forest owners will gradually respond by reducing their stocks of wood, either by planting less or by using their forests for other purposes. However, this adjustment is slow, due to the time lags involved in planting and growing trees, and even in the long run the adjustment may be less than complete.

Other models and assumptions could lead to other conclusions. Australia's National Greenhouse Gas Inventory notes that the greenhouse implications of forestry and land clearing are subject to particularly large uncertainties, and treats estimates in this area as more tentative than in other areas of analysis (Australian Greenhouse Office, 1999). The USEPA study (USEPA, 1998a), which I believe represents the best available US research on the subject to date, finds on the one hand that there are rather small energy savings due to paper recycling; that is, the second impact category, as discussed above, is of relatively little importance in this case. On the other hand, it finds that the forest sequestration savings due to recycling or reduction are quite large. On this basis, it finds paper reduction or recycling to be far better than incineration from a climate change perspective.

There are other opportunities for carbon sequestration in waste management and materials use, though they are on a smaller scale than in forestry. Carbon can also be sequestered in wood buildings and furniture, and in paper products. All of us who have not got round to cleaning out old file drawers full of forgotten papers are doing our bit to sequester carbon at home and at work.

A final, paradoxical form of sequestration should be mentioned briefly. In this case, I confess that I remain puzzled by the work of my colleagues on parts of the USEPA study. According to laboratory experiments done by one of the researchers, a noticeable fraction of the carbon in landfilled green waste and newspaper is never released, but remains sequestered indefinitely in the landfill. The same experiments showed almost no sequestration for landfilled office paper and food waste. For newspaper, landfill sequestration is smaller than the forest sequestration that results from recycling; the best thing to do with newspaper, from a greenhouse perspective, is still to recycle it. For green waste, there is no such alternative, so it is possible that net carbon emissions are somewhat lower when green waste is landfilled rather than composted. This result, which has surprised almost everyone, is based on only one set of laboratory experiments. It will be important to see whether it is confirmed by other researchers. The effect is not large in any case; it does not suggest that much progress could be made in reducing greenhouse gas emissions by landfilling more green waste. It does, however, cast doubt on past assumptions that composting is a natural strategy for reducing greenhouse emissions.

The final impact category is *energy required for transportation* of waste materials. If recycled materials are transported far enough, the energy savings from recycling may be offset by the energy consumed in moving the materials. In a worst-case scenario, sending recycled glass by truck from Perth to Sydney would undo most or all of the greenhouse benefits of recycling, since the truck emissions

TABLE 1. Changes in greenhouse gas emissions, relative to landfilling (tonnes of carbon dioxide equivalent emissions per tonne of material)

	Waste management option		
Material	Source reduction	Recycling	Combustion
Newspaper	− 2.7	− 2.5	0.0
Office paper	− 6.3	− 5.4	− 2.9
Cardboard	− 3.3	− 3.0	− 0.9
Aluminium cans	− 12.0	− 15.7	+ 0.1
Steel cans	− 3.4	− 2.3	− 2.0
Glass	− 0.6	− 0.4	0.0
HDPE containers	− 2.5	− 1.5	+ 0.8
LDPE containers	− 3.6	− 2.0	+ 0.8
PET containers	− 4.0	− 2.5	+ 0.9

Note: HDPE = *high-density polyethylene; LDPE* = low-density polyethylene; PET = polyethylene terephthalate.
Source: USEPA (1998a), exhibit 8–5, converted to metric tonnes of carbon dioxide-equivalent emissions per metric tonne of material. Figures shown here are the differences between emissions for landfilling and for each of the other waste management options. The landfill scenario used as a baseline assumes that 54% of landfills have methane capture systems, which are 75% efficient, implying that an average of 40% of all landfill methane emissions are captured.

would roughly negate the carbon reduction achieved in glass production. Note that this is a worst case: emissions are lower for long-distance freight transport by rail or by ship, and emission savings are lower for glass than for most other recycled materials. At the other extreme, recycling aluminium creates such huge per-tonne savings in energy and greenhouse emissions that the effects of long-distance transport are insignificant by comparison. The transportation effect can safely be ignored for recycling in most urban, industrial areas where distances to processing facilities are reasonably short. However, in low-density areas far from urban centres, such as western and northern Australia, the US inland West or New Zealand's South Island, the need for long-distance shipping of recyclable materials reduces their environmental benefit, at least from a climate change perspective.

Measuring the Impacts

How large are the greenhouse gas reductions achievable through waste management? Table 1 presents the estimates developed in the USEPA study, for nine recyclable materials. The table shows the change in emissions, relative to landfilling, for each material and each waste management option. A number of important patterns can be seen. Almost all the numbers are negative, indicating that almost everything is an improvement over landfilling from a climate change perspective. The only significantly positive entries in the table are for the incineration of plastics, which gives rise to air emissions. In contrast, plastics are inert in landfills, and do not cause any emissions.

For this study, landfills were assumed to recover 40% of all methane, an ambitious regulatory target that was far above the actual US average. With a lower rate of methane capture, landfilling of paper would look worse, and doing anything else with paper would look comparatively better.

The table shows that incineration is roughly as good as or better than landfilling for non-plastics, but is worse than recycling and source reduction for every material. The surprising climate change benefit from 'combustion' of

TABLE 2. Recycling of selected materials in 1996 (kg per person)

	Northern Sydney	US average	Seattle
Paper/paperboard	60	112	374
Glass	32	11	25
Plastics	1.8	3.6	2.7
Ferrous	0.3	15	10
Aluminium	0.2	3.5	4.1

Source: Northern Sydney (Australian Waste Database, 1999); US average (USEPA, 1998b); Seattle (USEPA, 1999b).

steel cans reflects the fact that incinerators recover and recycle much of the ferrous material they receive. Combustion of newspaper is no better than landfilling due to the assumption that landfilling of newspaper leads to long-term carbon sequestration. Without that assumption, landfilling newspaper would look worse, and all other newspaper options would look better.

Recycling of all nine materials leads to a reduction in greenhouse gas emissions, relative to landfilling. The benefits per tonne are greatest for aluminium and smallest for glass. Source reduction is even better than recycling, with the exception of aluminium. The explanation for this puzzle is that source reduction is assumed to replace the existing mix of virgin and recycled aluminium used in the USA today, while recycling is assumed to replace purely virgin material. Due to the large difference in energy intensity between virgin and recycled aluminium production, this means that the material being replaced is noticeably less energy-intensive for source reduction than for recycling.

Three Recycling Scenarios

The numbers in Table 1 tell us the per-tonne effect of recycling on greenhouse gas emissions (under US conditions and the numerous assumptions used in the study). These numbers can then be multiplied by the quantities of recycled material, in tonnes, to determine the total emission reductions attributable to recycling. I have assembled three sets of data on recycling for the purposes of this calculation, all for 1996:

- kerbside recycling in the northern Sydney waste management region, the region of Sydney with the highest per capita recycling rates (according to Australian Waste Database, 1999);
- the estimated US average level of recycling (USEPA, 1998b);
- recycling in Seattle, a well-documented success story of US recycling (USEPA, 1999b).

Table 2 shows the levels of recycling of selected materials in these three areas. The comparison is not entirely fair, since the northern Sydney data are for kerbside collection only, while the US data include all forms of recycling. More than two-thirds of Seattle's immense quantity of recovered paper comes from its commercial recycling programme. The differences between the Australian and US recycling rates reflect differences in the two countries' waste streams: Australians have more glass, while Americans have more metal containers, for example. However, as we shall see in a moment, nothing matters much for climate change except the quantity of recovered paper.

My final calculation consists of multiplying the numbers from Tables 1 and 2. Table 3 shows the reduction in greenhouse gas emissions due to recycling in each of the three cases, in kilograms of carbon dioxide-equivalent emissions per capita. Paper recycling accounts for 80% of the total reduction for the US average, and for more than 90% for both Seattle and northern Sydney. The totals are about 0.5 tonnes per capita at the US average, 1.5

TABLE 3. Greenhouse gas emission reduction due to recycling, 1996 (kilograms of carbon dioxide-equivalent emissions per capita, except as noted)

	Northern Sydney	US average	Seattle
Paper/paperboard	216	402	1348
Glass	13	4	10
Plastics	4	7	5
Ferrous	1	35	22
Aluminium	3	55	64
Total	236	504	1449
Total for 18 million people recycling at above rates (million tonnes of carbon dioxide-equivalent emissions)	4.3	9.1	26.1
Percentage of Australia's total greenhouse gas emissions	1.0%	2.2%	6.2%

Source: Recycling impacts per tonne from Table 1 multiplied by quantities from Table 2. Average of all three paper products in Table 1 used for paper/paperboard; average of plastics products used for plastics. Australia's 1996 total of 419 million tonnes of carbon dioxide-equivalent greenhouse emissions from Australian Greenhouse Office (1999).

tonnes at the Seattle rate of recycling and 0.25 tonnes at the northern Sydney kerbside rate.

The last two lines of the table present a further conjecture: how big would the impacts be if all 18 million Australians recycled at these per capita rates? The answer is shown in million tonnes of carbon dioxide-equivalent emissions, and finally as a percentage of Australia's total greenhouse gas emissions. If everyone in Australia, on average, recycled at the northern Sydney kerbside rate, then recycling would save 1% of Australia's total greenhouse gas emissions. If everyone matched the US average rate, the savings would be over 2% of the Australian emissions total. If everyone could keep up with Seattle's remarkable performance, more than 6% of Australia's emissions could be saved by recycling.

While these calculations are expressed in terms of Australian emissions, they apply with little change to US emissions as well. Although the USA still leads the global league in greenhouse emissions per capita, the Australians are among the toughest competitors, having achieved fully 96% of the US level by 1996. Thus the impact of the same nation-wide recycling rates on aggregate greenhouse emissions would be only 4% lower in the USA than in Australia. Calculations comparable to the bottom of Table 3 show that recycling (at the actual US average rate) saved 2.1% of the country's greenhouse emissions in 1996, while matching Seattle's recycling performance nation-wide would save almost 6% of total emissions.

These percentages may sound small. However, the reductions needed for compliance with the Kyoto targets are only modest percentages of total emissions. The calculations presented here suggest that ambitious programmes of recycling and waste reduction can make a substantial contribution to greenhouse gas reduction in Australia, the USA and elsewhere. The level of paper recycling, in particular, is of great importance for climate change mitigation.

Conclusion

More research is needed to solidify the numerous assumptions used in this analysis, and to develop appropriate estimates for planning purposes. The numbers presented here, with potential savings due to recycling ranging from 1% to 6% of national greenhouse gas emissions, are meant to illustrate the approximate magnitude of the effects of waste management, not to provide hard results for planning purposes. Among the crucial areas for further investigation are the actual rate of landfill methane capture, the impact of paper reduction and recycling on forest carbon sequestration, and the puzzling possibility of carbon sequestration in landfills. (Since this last puzzle is unresolved, no calculations have been included here for greenhouse impacts of composting.)

The effect of waste management choices on climate change appears to be large enough to be worth studying in greater detail. It is a subject well worth pursuing as we develop strategies for greenhouse gas reduction for the 21st century.

Note

{1} A version of this paper was presented at the Enviro 2000 Greenhouse Conference in Sydney, Australia, in April 2000.

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